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On Modularity in (V)Shorad Air Defense

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Summary

This paper addresses the concept of modularity in the context of (V)Shorads Air Defence.

Modularity is a technical concept that provides improved operational flexibility to (V)Shorad systems. Such improved flexibility is specifically relevant to mobile crisis reaction forces.

The discussion is largely qualitative and descriptive, given the premature state of modular technology in defence. The discussion is also largely applicable beyond air defence systems.

In this paper, it will be argued that modularity as a concept indeed addresses many of the problems facing mobile air defence today.

It will also be made clear that there are serious restrictions and drawbacks to modularity.

Further, it will be made credible that modularity is not a binary characteristic but a gradual one. This immediately raises the question how much modularity is required for what application.

Thus, the paper will provide fundamental insight into the use of modularity in mobile air defence.

Background

Air defence of (Multinational) Mobile Crisis Reaction Forces puts forth several specific requirements to the associated air defence systems.

Among other demands, it requires VShorads and Shorad air defence systems that are lightweight to allow both tactical and strategic mobility. It requires a traction system capable of traversing a diversity of terrain at good speed. It also requires that the air defence system can be used in a joint and/or combined environment. This will encourage a reasonable size of the overall international air defence deployment while minimising individual national contributions in the build-up of a multi-national crisis reaction force.

It will not be argued that these requirements compromise effectiveness and fighting efficiency of such systems as a result of engineering complications. Specifically, low weight incurs vulnerability to ballistics and structural integrity. High mobility restricts the choice of components because of size and requires additional ruggedness of systems. A joint-combined capability may require a plethora of communication, data and processing systems.

The obvious challenge for the air defence community is to devise an air defence concept that combines effectiveness with suitability for Crisis Reaction operations.

Paper presented at the RTO SCI Symposium on "System Concepts for Integrated Air Defense of Multinational Mobile Crisis Reaction Forces", held in Valencia, Spain, 22-24 May 2000, and published in RTO MP-063.

The solution to this challenge lies in *flexibility.* Flexibility in this respect denotes the use of a system that combines Shorads and VShorads and that does not have a fixed architecture or system composition. In a technical sense, flexibility is realised by the concept of *modularity.*

Modularity has been the subject of earlier studies, such as the NATO JPG-28/30 International Feasibility Study on Future VShorads and Future Shorads and several non-defence studies. In addition, the author has performed in-house research and discussions with Royal Netherlands Army and Air Force, resulting in the underlying paper.

This paper will first present the concept of modularity in general. Then, this concept will be applied to air defence systems, stating advantages and challenges. Finally, conclusions round up the discussion.

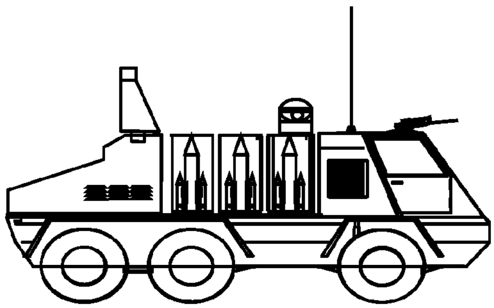

Figure 1. Representation of an integrated (V)Shorads air defence system, capable of autonomous operation. Picture taken [Ref.1].

Modularity as a concept

Any definition describing what modularity is can be a matter of debate. The following definition will serve its purpose for this paper.

Modularity is the concept in which a number of components of any system architecture, in this case a (V)Shorad system, can be combined repeatedly and relatively easy, to result in a large number of operational variants of a system, depending on the need as dictated by user, use and circumstances.

A few insights can be drawn from this definition.

First, this definition provides a hint towards benefits of modularity, namely the possibility to have more than one variant of a system.

Further, the definition also points out that modularity may be applicable to any number of components within a system. This implies that modularity is a gradual characteristic; a system is not either modular or non-modular.

Finally, the definition states that a modular system can be re-configured repeatedly and relatively easy, raising the question how 'relatively easy' is defined.

In order to be able to apply these considerations to (V)Shorads air defence, it is necessary to understand how a modular system is devised. The next section will provide this understanding.

The Architecture of modular systems

A system architecture can be thought of as having two at least two aspects of interpretation:

- A physical breakdown;
- A functional breakdown.

The physical breakdown is purely a technical matter dealing with subassemblies, production techniques materials, design, and 'nuts and bolts'.

The functional breakdown is a schematic indicating what functionalities are present in the system and how they interrelate.

The key issue to embed modularity in a system, is to maximise the similarity between the functional and physical breakdowns of a system.

For example, a very non-modular design is the wing of an aircraft. Physically, it is one entity, since although constructed from smaller parts, it cannot be taken apart sensibly. However, the wing performs multiple functions simultaneously: it lifts the aircraft, contains fuel, often suspends engines, contains control surfaces etc. etc.

By contrast, an example of a very modular product is LEGO, the building-blocks children's toys.

A number of significant advantages of the concept of modularity can be identified to improve future (V)Shorads if modularity is considered from the outset.

Operational advantages of modularity

Modularity provides the potential for two major benefits for the operational user:

- Construction of variants;
- Enhanced growth potential;

Likely areas of interests for a (V)Shorads air defence system are the following.

<u>Operational variants</u> are compositions of a modular system that have been tailored to a specific air defence mission, terrain environment, meteorological conditions, threat assessment and other operational issues.

Some examples to clarify are the following.

Example 1
An air defence mission in hilly or mountainous terrain may require an elevated sensor, in addition to vehicles' autonomous sensors. This could easily be a stand-alone jacked or tethered sensor. Of prime concern is only the interoperability in terms of organisation and information. This example represents modularity with modules on a relatively high level in the functional system hierarchy.

Example 2
A mission in areas of regularly poor weather may prefer a dual engagement capability, in terms of both IR and RF guidance. To incorporate both an IR and RF seeker into one missile may prove to be technically feasible but costly at the same time. A modular solution would feature a missile with a changeable seeker head and circuitry. A requirement would be that relatively poorly skilled operational personnel could do this routinely, within minutes. This example represents modularity on a level relatively low in the functional architecture.

Example 3
Assume that in a certain conflict, an NBC threat is anticipated. Continuation of operations then requires an NBC-proof air defence system. Or, an NBC-proof variant of a modular air defence system. NBC-proofing requires several measures in the system: NBC-proof crew compartment (pressurised), EM-hardened electronic equipment, blast protection and add-on decontamination/cleaning facility.

These are technical solutions, some of which can be applied by isolated modular building-blocks. If the crew compartment is stand-alone, it can exist in two variants. A cleaning facility is not necessarily physically integrated in the system, and blast protection can possibly be realised by add-on blast shields. This example represents a technically more challenging use for modularity.

Similarly, national variants may reflect national preferences such as a specific brand of vehicle, a gun/missile weapon mix, and rather important, a certain effective range for the sensor/weapon combination.

On a lower level, force variants may see specific preferences with respect to tactical mobility, interoperability standards, and support requirement.

The second major benefit is growth potential. Contemporary procedure for (V)Shorads equipment is to perform a Mid-Life Upgrade (MLU) after considerable service time, and numerous minor updates throughout the service life.

A key issue is that modularity in a system should allow replacement of modules without having to replace a higher-level or neighbouring module.

Modularity also provides the potential to:

- Incorporate new capabilities and technologies into the system;
- Incorporate technologies that are an improvement over the technologies already in the system;
- Replace components that have passed their service lives.

Other advantages of modularity include improved interoperability, enhanced potential for (physically) distributed operations, graceful degradation, smooth migration from legacy systems, common Human-Machine Interface and improved training, and maintenance and logistics. These will not be elaborated in this paper.

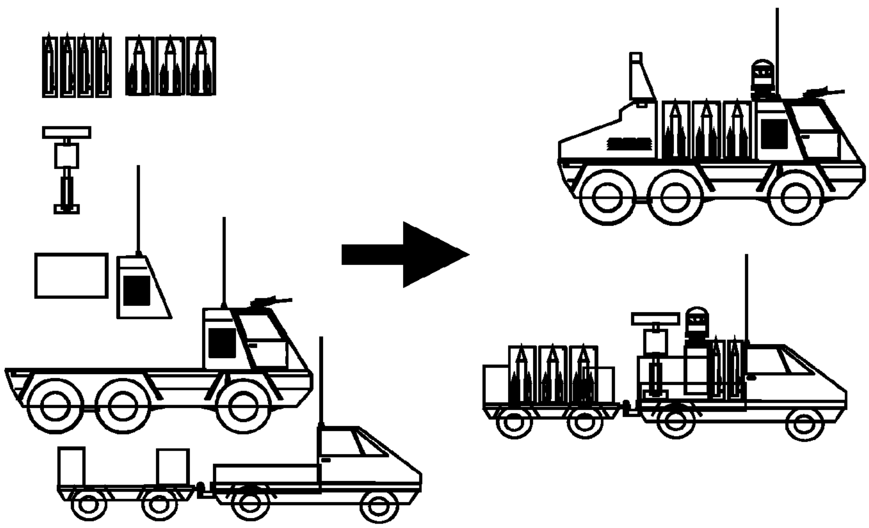

Figure 2. A loose set of modules is used to construct different operations, national or force variants, depending on mission need or specific user preferences. Picture taken [Ref.1].

Technical modularity

According to the previous sections, modularity is a promising concept. This section will elaborate on the realisation of the concept: technical modularity.

Technical modularity is the physical design that must make operational modularity possible.

First, consider two fundamentally opposite design principles:

<u>Specialisation</u> is initiated by the need to a improve a system's performance by optimising certain components and their interaction. This is often realised by for example combining functions (missile launch tube is also missile storage), removing redundancies, and dedicating and finetuning components to their specific function.

<u>Standardisation</u> is the opposite. It is aimed at broadening the scope of a components' applicability. It is often realised by incorporating redundancies, over-capacity and compromises.

Modularity is neither only specialisation nor only standardisation. Modularity combines the two. It allows specialisation by using standardised elements, called modules.

Technical modularity provides many advantages and disadvantages to industry.

Advantages include economies of scale, easier verification and testing, greater product line, reduced order lead time etc.

Disadvantages include [Ref. 2] a static product architecture, restricted product optimisation, ease of reverse engineering, increased unit variable cost, excessive product similarity and physical interface imposed design restrictions in terms of size, weight and shape.

For example, a modular missile launcher should be able to launch a multitude of missile types. This will either be a very large launcher to hold the largest of the missiles, or the missiles may not be larger than the tube. One way or the other, performance is compromised.

Further, interfacing is of crucial interest. An open architecture is required to accommodate a plethora of modules to be connected. It has been stated that whereas a modular system theoretically has an infinite service life, obsolescence of the interface is actually a firm show stopper to life extension.

A first step to realise interfacing that is suitable for a modular air defence system is a very well-defined functional and physical hierarchy. This requires exact knowledge of which elements, functions or capabilities are required to be modular. Interfaces also need to be highly standardised if multiple parties (nations, industries) are involved. Such interface specifications do not exist at present. Contemporary STANAGS are, in the view of the author, open to relatively wide interpretation.

Concluding, technical modularity is an enabler of operational modularity. It provides several technical challenges to be addressed.

Technical modularity also leads to sub-optimal component performance, and thus compromises operational effectiveness. Costs play a crucial role and will be discussed in the next section.

Cost consequences

Life Cycle Cost analysis is a delicate topic for any system. For modularity, the topic is even more difficult. How is the life cycle of a modular system defined? Theoretically, there is no end to the life cycle, since any worn module can be easily replaced without touching the remaining part of the system.

Further, primarily a cost comparison with non-modular systems is relevant at the present stage. But on what basis is the comparison made? With a non-modular system of the same effectiveness, with the same acquisition cost, or compared to any in-inventory system that is of national interest. Obviously, quantitative analysis is beyond the scope of this paper.

Some qualitative effects can be observed. Both cost savings and penalties result from modularity.

In a technical sense, economies of scale, greater production efficiency and greater product variety contribute to reduced acquisition costs. However, also increased unit variable costs apply and are a primary contributor to cost of modularity.

In an operational sense, growth potential reduces replacement costs, and is a long term effect. LCC of a modular system is also strongly dependent on acquisition strategy, ranging from a custom-made set (i.e. an integrated (V)Shorads based on a modular design) to a loose set of modules procured over time (first a basic set to complement legacy systems, then additional modules such as sensors, warheads and others).

One single contractor, supplying to many different nations from a single pool of modules represents the absolute ideal situation, taking all the benefits whilst maximising cost savings.

It is very unlikely however, that such an international process can be substantiated at present, given the limited economic, industrial and political integration in Europe.

A solid conclusion can not be drawn, other than to state that perhaps contradictory to expectations, it is definitely not guaranteed that a modular (V)Shorads air defence system has reduced Life Cycle Costs.

Before setting out on a LCC comparison, it is recommended to devise a proper comparison methodology first.

On the amount of modularity

This paper so far addressed the operational benefit, the technical realisation and the cost consequences of modularity. These sections implicitly addressed both totally modular versus totally non-modular systems. However, it has already been stated that modularity is not a binary characteristic, but a gradual one.

Consider a system consisting of larger components (sensors, weapons), minor construction elements (computer memory chips) and anything in between. Now consider that any of these can be theoretically denoted as module.

Appointing any element as a module leads to <u>additional</u> specifications for that element. For example, the earlier example of dual interchangeable missile seekers requires that the two seeker are of the same (external) size and shape. It is also required that they are within man-portable weight limits. Such additional requirements are needed to ensure seamless integration of the module into the system.

Obviously, the higher the relative number of modules, the more modular the system will be.

The amount of modularity is therefore a variable scale with two extremes.

On the high end of the scale, an integrated (V)Shorad system can be considered as one single module. This can be a quite capable system.

On the lower end of the scale, a seemingly irrational collection of bolts, nuts, chemicals and other ground materials is a very, very modular system. This obviously will not make a very effective air defence system.

The obvious conclusion is that increasing the number of modules and thus the degree of modularity is not necessarily a good thing. Careful selection and optimisation are in place.

Such an optimisation has not been carried out on behalf of this paper. However, from discussions and expert opinions, there seems to be agreement that modularity should be applied at a fairly high functional level, in order to be technically feasible and operationally useful.

For example, the (V)Shorads major functional breakdown into four functions as follows may be a suitable level for applying modularity to:

- Surveillance;
- Tracking;
- Shooting;
- Moving.

It would be worthwhile to investigate the technical feasibility of modularity on this level. A next step would be to explore modularity one level down the hierarchy.

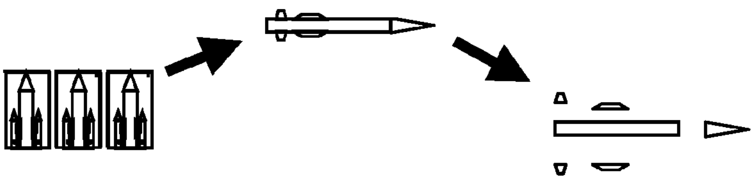

Figure 3. Modularity on a low level in the system architecture, such as applying a varying set of control vanes to a missile, is unlikely to give overall benefit. Increased element variable costs resulting from over-specification is paramount. Picture taken [Ref.1].

Control

A final issue to consider is the party having control over modularity. For example, it may be desirable that the user, i.e. the man in the field, can control his system. For low-level modularity such as changing seeker heads according to variations in threat or weather, it is undesirable to have to ship the system back to industry. The operational capability would be compromised immediately and a force planners' job would become impossibly difficult.

On the other hand, it is extremely undesirable that front line air defence troops are required to physically integrate an additional sensor into a system.

This issue has not been addressed in any other source on modularity in defence. Since it has a major impact on operations, it deserves proper attention.

Conclusions

The following conclusions can be drawn from the preceding sections.

1. Modularity is a technical solution to provide operational flexibility of (V)Shorad air defence systems.
2. Modularity is applied to a system by appointing selected elements as modules. This will lead to additional interfacing requirements for that element.
3. Accordingly, isolated element cost is likely to increase and isolated element performance may decrease. Technical complications and increased acquisition cost are likely.
4. However, the long-term net effect may be a reduction in Life Cycle Cost, improved growth potential and improved overall performance over wide range of threats and circumstances.

Recommendations

For continued research into modularity, two recommendations have been made and are repeated below.

1. For Life Cycle Cost studies, it is recommended to first devise a suitable methodology for comparing LCC between modular and non-modular air defence systems.
2. For establishing the optimum amount of modularity for an air defence system, a top-down approach is recommended, starting with modularity at a high functional level.

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